NASA TECHNICAL TRANSLATION

NASA TT F-11,906

NASA TT F-11,906

X-RAY DOSIMETER

G. Massiot & Co., France (Seine).

Translation of "Dosimetre à rayons X".
French Patent No. 1,035,715. Published in Paris, 1953.
5 p.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 AUGUST 1968

NASA TT F-11,906

X-RAY DOSIMETER

Company: G. Massiot & Cie, residing in France (Seine)
French Patent No. 1,035,715

ABSTRACT: The invention concerns dosimeters for measuring the intensity of the dose, or both, of X-or gamma rays administered to a body at a given location. The essential characteristic consists of a cell whose part sensitive to X-or gamma rays consists of a semiconducting layer or material, and in the fact that this cell is mounted in a suitable circuit for measuring variations of the resistance of this cell under X-or gamma radiation.

The present invention concerns dosimeters for measuring the intensity or integral dose of X-or gamma rays at a given location. /1[1]

Present day dosimeters have the following disadvantages:

1. The ionization chambers, which constitute an integral part of all known modern dosimeters, require the maintenance of a very high insulation, namely, a leakage resistance of the order of 10^{12} - 10^{15}ohms, which necessitates a whole special technique for constructing the chamber, for connecting it to an electrometer tube, and for the construction of this tube itself;

2. The cost of these dosimeters is consequently rather high, and the dosimeters are subject to rather frequent breakdowns caused in particular by a deterioration of the insulation and by failures of the electrometer tube, which is particularly fragile from the electrical and mechanical points of view;

3. In order to obtain a sufficient sensitivity for medical applications, the chamber must be given dimensions which are cumbersome for its manipulation, especially when it is necessary to introduce the chamber into constricted areas, in particular, body cavities. The cumbersomeness of the chamber is still greater in cases where it is necessary to look for leakage radiation fields, in view of the very high sensitivity required for detecting a very weak radiation.

In order to avoid these drawbacks, the present invention utilizes semiconducting layers, chosen and prepared for the particular purpose of obtaining suitable qualities under X-or gamma irradiation, as will be explained in detail below, these layers being used to measure the X-or gamma radiation.

Described below in more detail will be examples of the execution of the invention in reference to the attached figures, in which:

Figures 1 to 7[2] show, as nonlimiting examples, possible designs of a measuring cell containing the semiconducting layer or material sensitive to X-or gamma rays;

---

[1]Numbers in the margin indicate pagination in the foreign text.
[2]Figures are omitted from translation.

Figures 8 to 14 show examples of measuring circuits in accordance with the inventions; and

Figures 15 and 16 show curves of absorption of X-rays by two different chemical elements.

Figure 1 shows a conductor 1 covered with a semiconducting layer 2 and inserted into a conductor tube 3. A spacer 4 provides a suitable distance and sufficient insulation between conductors 1 and 3.

Figure 2 shows a semiconducting material mounted in the form of a cylinder 5 filling the bottom of tube 3, while a metallic or metallized lug 6 rests on semiconducting material 5 and makes contact with it through the action of a spring or some other elastic device and the conductor 7 connected to wire 1.

Figure 3 gives an example of a design of the cell in the form of a needle. Elements 1-3-5 correspond to those of Figure 2, whereas the point of the needle is indicated in 8. This figure indicates another form of the contact between elements 1 and 5: wire 1 has a head 9 which penetrates more or less into the semiconducting material 5.

Figure 4 shows another design of the cell. As in Figure 1, it indicates two conductors 1-3 and semiconducting layer 2. The latter is surrounded by a conducting layer 10 whose contact with tube 3 is provided by a lug or spring 11.

Figure 5 shows a variant of the design indicated in Figure 4, the contact between conducting layer 10 and tube 3 being provided by a binding conducting /2
material 12 filling the round bottom of tube 3.

Figure 6 indicates at 13 a semiconducting material in the shape of a die or a sphere or a similar shape, electrodes 14 and 15 each covering a part of the surface of material 13. Conductors 16 and 17, which make contact with electrodes 14 and 15 respectively, permit measurement of the resistance of material 13.

Figure 7 shows a cross section of a semiconducting material 18 between two electrodes 19 and 20 whose surfaces, in contact with the semiconductor, are enlarged by the rough areas and cavities which penetrate into one another.

Figure 8 shows an example of a measuring circuit; 21-22-23 indicates the essential elements of a semiconducting cell which correspond to elements 1-2-3 of Figures 1 to 5, and 24 indicates the incident X-or gamma radiation whose intensity or integral effect during a certain time period is to be measured. Electrodes 21 and 23 of the cell may be connected to a standard dosimeter, taking into account the lower resistance of the semiconducting layer or material 22 as compared to the case of a common ionization chamber.

In this Figure 8, an ordinary dosimeter is indicated by 25, the input tube, electrometric or other, is indicated as an example by 26, the grid is indicated by 27, the cathode by 28, and the anode of this tube, by 29. A capacitor 30 may be connected in parallel to the semiconducting cell. The other parts of the dosimeter are not indicated.

Figure 9 shows a circuit which permits the measurement of the resistance of the cell 21, 22, 23, variable with the radiation 24, by applying to the cell an electric voltage whose source is indicated in 31. A microammeter 32 or an amplifier followed by a measuring instrument make it possible to measure the current passing through the cell.

Figure 10 indicates another measuring circuit in the form of a bridge, where 33, 34 and 35 indicate the resistances, some or all of which are variable, and which form the four branches of the bridge with cell 21-22-23. The voltage source is indicated in 36, and the measuring instrument, which may include a suitable amplifier, is indicated in 37.

Figure 11 shows a measuring bridge similar to that of Figure 10, where the resistance 35 of Figure 10 is replaced by a compensating cell 41-42-43, whose design is identical to that of cell 21-22-23, but which is nevertheless enclosed in a protective cage 40 in order to shield it from X-or gamma radiation. A curved source is indicated by 38 and a current measuring instrument by 39.

Figure 12 indicates a compensating cell 41-42-43 enclosed in a protective cage 40 and connected to the bridge in the same manner as in Figure 11, with the protective cage containing, in addition to this cell, a radiation source 44 whose radiation, directed on cell 41-42-43, may be attenuated by a shield 45.

Figure 13 indicates by 46-47-48 a compensating cell, preferably enclosed in a protective cage 40 and connected to a measuring bridge in the same manner as in Figures 11 and 12, cage 40 containing, in addition to the cell, on the one hand a radiation [redacted] 49 supplied by a voltage source 50 in a manner adjustable by a resistance 51, with measurement of the supply curved by an instrument 52, and, on the other hand, a photoelectric cell 53 which is supplied by source 54, the luminous flux received by this cell being measured with instrument 55. Arrows 56 indicate the luminous radiation originating from source 49.

Figure 14 shows the design and circuitry of a double cell 1-2 indicating, as in Figures 1 to 5, the external conductor and the semiconducting layer respectively. As in Figure 5, the conducting layer deposited on semiconductor 2 is indicated by 10, and the conducting material interposed between layer 10 and the external conductor (corresponding to conductor 3 of Figure 5) providing the contact is indicated by 12. The external conductor is represented in Figure 14 by a conducting layer 57 deposited on the inner wall of an insulating tube 58. Layer 57 and conductor 1 are connected to the measuring bridge in the same manner as in Figure 10, the numbers 33, 34, 36, 37 indicating in Figure 14 the same elements as in Figure 10, namely, two bridge resistances, the supply of the bridge, and the measuring instrument respectively. The fourth bridge resistance, diametrically opposed to cell 1-2-57, is constituted by another cell whose semiconducting layer is indicated by 59 in Figure 14, the external

contact being provided by a conducting layer 60 deposited on the external surface of insulating tube 58, whereas the external contact is provided for by a conducting layer 61 deposited on the semiconducting layer 59; the external tube 62, preferably metallic, acts simultaneously as the external contact connected to the bridge and as the casing of the double cell. Variable resistances are /3
indicated in 63 and 64.

Figures 15 and 16 show absorption curves for the X-radiation of two elements differing markedly in atomic number in the periodic system; the wavelength is marked off along the abscissa axis 65 and the absorption along the ordinate axis 66. Curve 67 of Figure 15, corresponding to lead, shows abrupt variations in absorption 68 and 69 which (for heavy elements such as lead) are located in the wavelength range pertaining to the application of X-rays, whereas similar variations for light elements such as carbon are located substantially outside this range, namely, in the range of very long wavelengths; the curve corresponding to carbon is indicated by 70 in Figure 16.

According to the invention, the cell sensitive to X-or gamma rays is essentially composed, as represented by the nonlimiting example of Figure 1, of two conductors or electrodes (1 and 3), one preferably in the form of a metallic or metallized wire, and the other in the form of a sheath or a metallic or metallized tube, and, between them, of a semiconducting layer or material. In the case where a semiconducting liquid filling the entire space between wire 1, tube 3, and spacer 4 is used, spacer 4 can at the same time be used to seal the cell. The same semiconductors which are sensitive to light are also known to be sensitive to X-rays, in the sense that their electrical resistance varies with the radiation intensity. However, since the absorption of a semiconducting layer is much lower for X-radiation than for luminous radiation, it is important to apply layers that are much thicker for a cell in accordance with the invention than in the case of common photoelectric cells. The best known semiconducting products used exclusively in photoelectric cell technology are sulfides of zinc, cadmium, selenium, tellurium, and lead. It might appear useful to select elements of as high an atomic weight as possible in order to obtain an increased absorption of X-rays, in view on the one hand of certain difficulties involved in fabricating semiconducting layers that are sufficiently uniform and have a thickness greater than a few microns, and on the other hand the rapid increase of the absorption with the atomic weight, or more exactly with the atomic number of the element in question in the periodic system. Although this is valid for layers used in photoelectric cells and screens of brightness amplifiers, whatever the spectrum employed, this is not the case for purposes of dosimetry. Since the elements show discontinuities in the absorption curves as a function of wavelength, such as those appearing in Figure 15, namely, abrupt and pronounced variations in absorption, located at wavelengths which decrease as the atomic number of the element increases, the absorption of heavy elements varies appreciably and irregularly with the wavelength, whereas the absorption of light elements increases slowly and uniformly in the range pertaining to the application of X-rays. Since living tissues consist virtually exclusively of light elements such as hydrogen, oxygen, nitrogen, and carbon, a response of a dosimeter analogous to the response of these light elements is an indispensable condition, particularly since the radiation originating from

X-ray tubes always covers a broad wavelength range, and since the energy distribution over the spectrum is appreciably modified in the course of penetration of the rays through matter.

According to the invention, the products suited for the construction of a dosimeter consist of light elements, namely, first of all semiconductors with a base of sulfur or magnesium oxide, beryllium (glucinium), aluminum, for example, secondly of certain organic products belonging to the family of luminescent substances (for example, naphthalene, anthracene), and finally certain liquids whose resistance may vary appreciably with the intensity of X-radiation.

These products, all subsequently grouped under the general name of semiconductor exist in various forms such as liquids, powders, solid crystalline lumps, crystals, thin layers deposited by evaporation, sublimation or cataphoresis, and it thus becomes necessary to select an appropriate design of the cell for each form. Thus, the designs of Figures 1, 4 and 5 lend themselves to processes where the internal conductor 1, for example a metal wire, may be surrounded by a relatively thin layer of semiconducting material, whether it is deposited by evaporation, sublimation, or cataphoresis, or whether the wire is immersed in a solution or melt of the semiconducting material. On the other hand, the designs of Figures 2 and 3 are advantageous if the semiconducting /4
material is in the form of a powder or polycrystals, whereas the design of Figure 6 is reserved for solid lumps, preferably single crystals. The material constituting the fittings of the cell, such as the internal and external conductors, should be, according to the invention, of a reduced mean atomic weight, and in any case should not appreciably exceed that of the living tissues, for the reasons indicated above.

Because of the small size of the semiconducting materials, especially in the form of layers, it is possible to construct very small cells, this being of the greatest interest, particularly from a medical point of view. According to the invention, as indicated in Figure 3, the external tube can be made in the form of a needle in order to be able to introduce the cell into the living tissue as an injection. The needle may be coated with a very thin layer of a medically suitable metal, so that this layer does not affect the operation of the cell.

Semiconducting materials whose resistivity may vary between 10^3 and 10^{16} ohm/cm show variations in resistivity when acted upon by incident X-radiation, so that the magnitude of the resistance of a cell described above represents a measure for the intensity of the radiation in question at the location of the cell.

Although the ratio of the radiation intensity to the resistance is not always linear, one readily finds products whose characteristic of the resistance as a function of the radiation intensity is approximately linear, at least over a relatively broad range, preferably for a weak radiation, this being frequently of the greatest interest.

To obtain a suitable resistance, especially with semiconducting materials of very high resistivity, it may be of interest, according to the invention, to provide for an adequate contact over a large surface of the semiconductor by depositing on the latter a conducting layer (10 in Figure 4), for example, made of a material based on an aqueous colloidal solution of graphite such as the one known by the name of "aquadag" or made of a metal deposited by evaporation or cataphoresis. It may also be advantageous, still according to the invention, to increase the surfaces of the cell electrodes as indicated in Figure 7 as a nonlimiting example.

In order to measure the variation of the cell resistance under the action of X-rays, the cell can in principle be connected directly to a common dosimeter in place of an ionization chamber. However, the resistance of the cell being much lower than that of an ionization chamber, the input circuit of the disometer must be adapted to the resistance of the cell, in particular, by connecting a capacitor 30 in parallel with the semiconducting cell, as indicated in Figure 8.

In the simplest case, in order to measure the cell resistance, one can use a circuit whose diagram is shown in Figure 9. A voltage, continuous or alternating, is applied to the cell by placing in series a measuring instrument, either a microammeter to make a direct measurement of the current passing through the cell, and representing a measure of the intensity of the radiation striking the cell, or an amplifier followed by a measuring instrument. The latter case may impose itself if the resistance in the cell is sufficiently high and if at the same time it is necesary to apply a relatively low voltage to the cell, namely, a voltage of the order of a few volts or even less, in order to insure a linear response of the cell. If necessary, one may use a nonlinear amplifier of a characteristic such that it automatically straightens out the response curve of the cell. In order to permit an easy manipulation of the cell, the latter will be attached to a flexible cable, preferably a coaxial one, whose leakage resistance should be appreciably higher than that of the cell.

Another method of measurement is indicated in Figure 10, where the resistance of the cell is part of a measuring bridge. The advantage of this circuit consists in the fact that in order to obtain a precise measurement of a given radiation, it is possible to vary one of the resistances 33, 34 or 35 until the measuring instrument 37 is brought to zero. The resistance varied in this manner may be readily standardized immediately to give the radiation intensities received by the cell. Thus one can avoid the control and adjustment of the amplifier required for a direct measurement.

The resistance of semiconducting layers frequently depends substantially on the temperature. To avoid an influence of this effect on the measurement of radiation, the invention stipulates the connection of another cell, more or less analogous to the measuring cell as such, in place of one of resistances 33 or 35 in Figure 10, as shown in Figure 11. The compensating cell 41-42-43 should be sufficiently protected from any X-radiation by a cage 40, for example, /5
made of lead and having a suitable thickness. It is also possible, according

to the invention, to use the compensating cell without shielding, the cell being attached at the end of a cable, as is the measuring cell.

By placing the two cells in different locations, one can measure the difference between the incident radiations at the two chosen locations.

In the case where very precise measurements are required, or when the response of the cell is not sufficiently linear, use may be made, according to the invention, of the assembly shown in Figure 12. Compensating cell 41-42-43, still enclosed in protective cage 40, will be exposed to a source 44 (Figure 12) emitting radiation, preferably X- or gamma rays. A screen 45 of adjustable absorption, for example a lead disc of a thickness which is variable around its circumference or a wedge, makes it possible to adjust this compensating radiation so that the instrument of reading 37 or 39 (see Figure 10 and 11) is brought to zero. The positions of the screen can be standardized directly in terms of the intensity of radiation striking measuring cell 21-22-23.

A variant of the assembly is shown in Figure 13. Here, compensating cell 46-47-48, constituted by a thin layer which will receive luminous radiation, is subjected to any luminous radiation 56 originating for example from an incandescent filament 49, the latter causing the resistance of the compensating cell to vary in a manner analogous to that of X rays. By varying the brightness of the light source 49 by means of resistance 51, one can bring the measuring bridge to zero. The intensity of the heating current, which is read off with instrument 52, represents a measurement for the X-radiation received by measuring cell 46-47-48, and instrument 52 can be standardized directly in terms of X-radiation intensity. It may be advantageous, particularly from the standpoint of the linear response of the set, to measure the luminous radiation, still according to the invention, with an ordinary photoelectric cell 53 whose response is strictly linear. The reading is then taken with instrument 55 in the circuit of the photoelectric cell.

According to the invention, it may be advantageous, particularly from the standpoint of the sensitivity of measurement, to have two measuring cells placed at two opposite branches of the measuring bridge. The two cells should then be combined so that they are essentially at the same location where the radiation is to be measured. As an example, Figure 14 shows a double cell according to the invention. In Figure 14, starting from conductor 1 inside, one successively finds semiconducting, conducting and insulating layers as described above, so that the two cells, one surrounded by the other, can be connected to the four terminals of the measuring bridge. It is obviously possible to combine one double cell with one of the compensating cells of Figures 11, 12 and 13 or with a double compensating cell. In these cases, additional resistances should be connected to the bridge, preferably in series with cells, as indicated by 63 and 64 in Figure 14.

Translated for the National Aeronautics and Space Administration under contract No. NASw-1695 by Techtran Corporation, P. O. Box 729, Glen Burnie, Maryland, 21061